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Alarming decline of the Little Bustard *Tetrax tetrax* in one of its two population strongholds in Sardinia, Italy

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Research Article

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Summary

Farmland biodiversity is declining worldwide, and especially in Western countries largely owing to the large-scale intensification of agricultural practices. The Little Bustard *Tetrax tetrax* is a steppe bird adapted to agro-pastoral ecosystems in Western Europe, and is one of those many farmland species declining due to changes in agricultural production systems. In the EU, the majority of the extant population of this species is concentrated in the Iberian Peninsula. In Italy, the species has now disappeared from the mainland and is currently present only in Sardinia, where two populations, in the central-western areas, hold about two-thirds of the whole island's numbers, with the rest scattered across numerous smaller nuclei. While there are indications and anecdotal information suggesting a possible population decline during recent decades, robust monitoring across different time periods that would allow a comparison of numbers is lacking in Sardinia. Here we repeated a Little Bustard survey performed in 2008 in two areas of western Sardinia: Abbasanta, which is one of the two strongholds for the species in Sardinia, and Campeda, which holds a small population (about 10 territorial males). Using the same methodology as in the past survey, we assessed current population size and density, and quantified changes over time. We found alarming declines, at a rate of around 30% in 14 years in both areas, with an estimated current population of 87 males in Abbasanta and 8 males in Campeda. We highlight current and emerging threats, such as the downsizing of the Special Protection Area of Abbasanta, and the encroachment of solar power plants within the same area.

Introduction

The collapse of global biodiversity and ecosystems has reached such a magnitude and scale that we are now witnessing a sixth mass extinction wave (IPBES 2019). Among all biodiversity, the decline of bird populations is perhaps the best documented, with approximately 48% of the world's ~11,000 species having experienced known or suspected population declines (Lees *et al.* 2022). However, such declines are not equally spread across the world's birds. Notably, grassland species present the most severe declines among all North American bird species (Rosenberg *et al.* 2019). Similarly, farmland birds in Europe have declined precipitously over recent decades, largely due to the intensification of agricultural practices (Gregory *et al.* 2019, Pain and Pienkowski 1997).

The Little Bustard is a species adapted to traditional ("extensive") farming landscapes which has suffered one of the most severe population declines in Europe (Morales and Bretagnolle 2022). It is classified as "Near Threatened" globally, "Vulnerable" in Europe (source: www.iucn.org), and "Endangered" in Italy (Gustin *et al.* 2019). During the second half of the twentieth century it disappeared from 15 countries, with the western Palearctic population now restricted to the Iberian Peninsula, France, and Sardinia (Morales and Bretagnolle 2022). In the Iberian Peninsula, the western stronghold for the species, a yearly population decline of 6% has been quantified over the past two decades (Morales and Bretagnolle 2022). Similarly, in Sardinia, which holds the last extant population of the species in Italy, the species is thought to be declining (Morales and Bretagnolle 2022), but the trend is highly uncertain due to a lack of comparable data over different time periods. Populations in mainland Italy and Sicily went extinct during the past century (Morales and Bretagnolle 2022). In Sardinia, the Little Bustard was largely distributed across the extensive pastoral and arable landscapes in the central-western part of the island, with an estimate of 1,500–2,000 individuals in the mid-1980s (Schenk and Aresu 1985). In 2010–2011,

an extensive survey across the island resulted in the detection of only 352 males (Nissardi and Zucca 2011), underscoring a potentially large decline. By then, only two main population strongholds remained in the island, one on the plain of Ozieri (Special Protection Area id. ITB013048), and the other on the plain of Abbasanta (Special Protection Area id. ITB023051). These two nuclei were estimated to support about two-thirds of the whole island's population, with the rest of the birds scattered among a few smaller nuclei (Nissardi and Zucca 2011).

Unfortunately, no later surveys of the species have been carried out, hindering quantification of the species current status and population trend in Sardinia. This lack of information is all the more worrying given the general decline of the species across its western range in Europe (Morales and Bretagnolle 2022). In Sardinia, as in most other regions, there is a growing interest for developing previously rural and traditional pastoral areas through the expansion of wind and solar energy plants, as well as mining and other extraction activities and land uses (Silva *et al.* 2022). Such changes, like solar power plants, may cause direct habitat loss to the Little Bustard, which may not be safe even within the current Special Protection Areas (SPAs).

Given the status of the species in Europe, there has been an urgent need to assess the current population status and trend on Sardinia. In response, we set out to repeat, using the same methodology, the previous survey undertaken in 2008 (Santangeli and Dolman 2011), across two areas in Sardinia. This is the first time that a survey has been replicated with the same methodology, allowing a robust and reliable comparison between results, and the quantification of the change in the status of the species in Italy. These findings are discussed in light of recent land use and other changes in these areas. We also identify potential emerging threats to the species in Sardinia, and review the implications for the conservation of this relict but vitally important and restorable population.

Methods

Study area

The study took place in central-western Sardinia, focusing on two highland plateau areas extensively surveyed in 2008 (Santangeli and Dolman 2011). Both areas, which fall within the Natura 2000 network, are SPAs designated for the conservation of the Little Bustard under the European Commission Directive 79/409/CEE, namely, the plain of Abbasanta (hereafter Abbasanta) and the plain of Semestene, Bonorva, Macomer e Bortigali (ITB023050) (hereafter Campeda, following the names used by Santangeli and Dolman 2011) (Figure 1). Both areas of the current study have the same boundary as those from the earlier study (Santangeli and Dolman 2011). We did not cover the second stronghold, the plain of Ozieri, in this study, as it was not covered in the 2008 survey, thus lacking comparable data. The study of Santangeli and Dolman (2011) also covered a third lowland area, central Campidano, which was excluded from the current study for logistical reasons. The two areas of Abbasanta and Campeda comprise similar landscapes dominated by semi-natural steppe with extensive pastures, long-term fallows, hay meadows, and, to a lesser extent, dry cereals (Santangeli and Dolman 2011). Despite the similar landscapes, Abbasanta supported high Little Bustard densities (2.7–3.4 males/100 ha), and is one of the two identified strongholds of the species in Sardinia (Nissardi and Zucca 2011), while Campeda supported very low densities (0.1–0.2 males/100 ha) (Santangeli and Dolman 2011).

Land-use data

We wanted to compare land use between the two systematic survey periods: 2008 and 2022. For the survey in 2008 a land-use map specifically produced by the Region of Sardinia was available, and from which the amount of suitable (pasture and cropland,

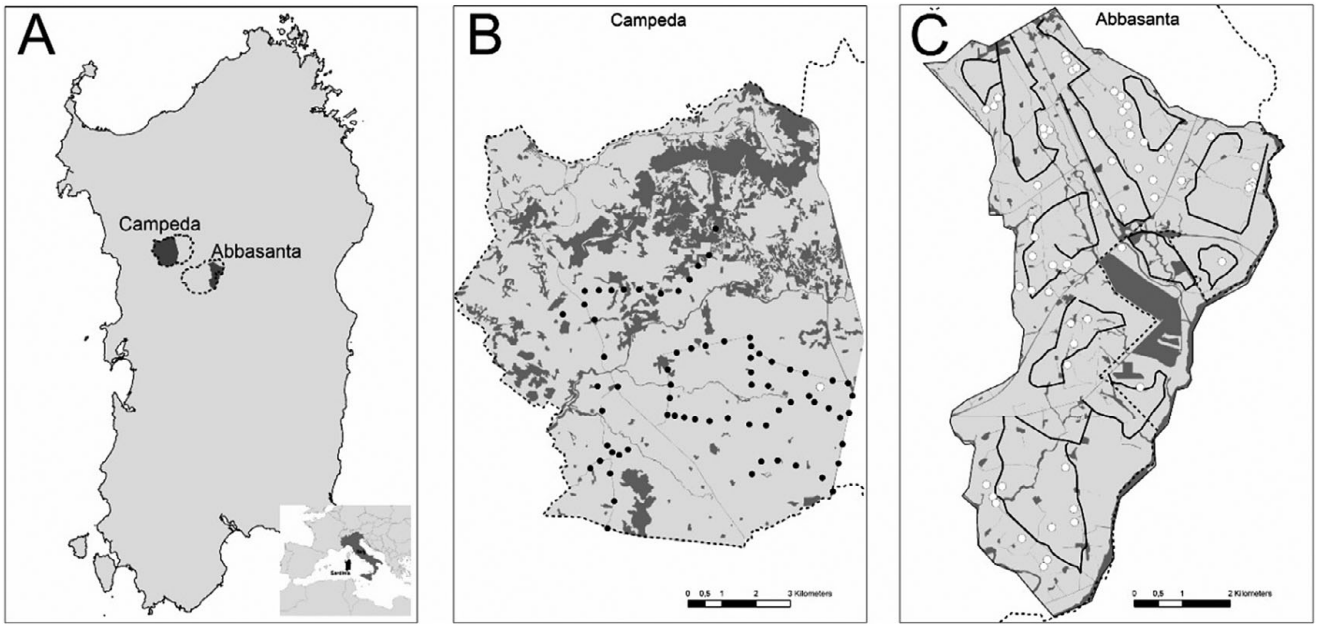

Figure 1. (A) The location of the two study areas (dark grey areas) considered for this study within Sardinia, with reference to the two Special Protection Areas (SPAs) (dashed lines). The inset at the bottom right shows the location of Sardinia (black), in Italy (dark grey), located within the Mediterranean Sea. (B) and (C) show the land cover (light grey as suitable and dark grey as unsuitable habitat), as well as the point count (black points in B) or transect line (dark thick lines in C) locations, with male detections shown as white circles. The boundaries of the SPAs are shown with dashed lines.

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including arable, hay meadows, and fallow) and unsuitable (villages, infrastructures, vineyards, woodlands, and any other woody vegetation area) habitat for the species was calculated (Santangeli and Dolman 2011). However, there was no comparable and updated land-use map for more recent years. Therefore, we decided to update the land-use map of the two study areas for 2022 using the most recent orthoimagery available from the Region of Sardinia (Ortofoto AGEA 2019). This is the same type of product used for creating the 2008 land-use map. From the orthoimagery we manually updated the land use (separating suitable from unsuitable based on the same criteria used for the 2008 study), which was then ground-truthed using available photographs from Google Street Maps and from fieldwork during the surveys.

Little Bustard sampling

We set out to repeat, as closely as possible, most transects (Abbasanta) and point counts (Campeda) conducted in 2008 (Santangeli and Dolman 2011), using the same survey methods. While the 2008 study used a mixture of line transects and point counts at both sites, and analysed them separately, we only performed line transects in Abbasanta and point counts in Campeda, for simplicity and logistical reasons. The above choices are logistically reasonable because Campeda is a large area with low densities of Little Bustard, where point counts could be conducted along drivable dirt and tar roads. This minimised the time needed for observers to move between points while maximising the survey area coverage. Conversely, Abbasanta is a smaller area where many dirt roads have restricted access for driving. Therefore, in these conditions, walking transect lines represented the most efficient survey method. It is however important to note that these choices of survey method did not affect the comparability of the estimates from the two surveys, because the estimates were calibrated on survey effort in each case. That is, the number of males detected was divided by the effective surveyed area of suitable habitat in each site, in the same way as in 2008. Surveys took place between 1 May and 11 May 2022, the peak of male display activity in Sardinia and centred within the study period of the earlier survey. As in the earlier study, surveys were conducted after dawn (06h00 to 09h30) and before dusk (18h00 to 21h00) under favourable conditions of no rain or wind (Wolff *et al.* 2001). The above choice followed from known activity patterns of the species (de Juana and Martínez 1996). Transect lines in Abbasanta ($n = 9$ transects) were approximately 7 km long, typically separated by a minimum of 500 m distance, and walked at slow speed (2 km/h). Point counts in Campeda ($n = 70$ points) were spaced at least 500 m from each other, with a five-minute duration for each. We applied distance sampling (Buckland *et al.* 2015), as in the earlier study (Santangeli and Dolman 2011). The distance (radial for point counts and perpendicular for line transects) of each detected male Little Bustard was recorded to the closest 10 m.

Density estimation

We used the Distance 7.4 software (Buckland *et al.* 2015) to estimate the effective strip width (ESW) for line transects (available from the Abbasanta site only). We tested the half-normal, hazard -rate, and uniform-cosine functions, and selected the results from the best fitting model, that is, the one with the lowest Akaike information criterion (AIC), following Santangeli and Dolman (2011). In this case, the best fitting model was the one with the hazard-rate function. From that model, we derived the ESW with 95% confidence interval (CI) distances, and used these distances to create buffers around the transect lines in order to calculate the effectively surveyed area (with 95% CI) in a Geographic Information System (GIS) environment (using ArcMap 10.8 ©ESRI). For Campeda we detected only one male from all point counts, which did not allow us to run distance sampling analyses to derive the effective detection radius (EDR). Therefore, we used the EDR with 95% CI available from point counts in the same area from Santangeli and Dolman (2011). While this is a suboptimal solution, it still allowed us to obtain comparable densities and population estimates under the assumption that the detection function (and especially the EDR) for point counts had not changed from that of the earlier survey. To validate this assumption, we compared the ESW from the present survey (mean ESW = 286 m, 234–349 95% CI) with the ESW reported in the 2008 survey (mean ESW = 227 m, 180–285 95% CI) (Santangeli and Dolman 2011). The fact that these ESWs were comparable indicated that detectability of the species in these areas has remained similar. This gives us confidence in the approach used and in the validity of the assumptions as detailed above.

Density and population estimates were thereby obtained from the number of detected males, suitable area surveyed (calculated as detailed above), and the extent of available habitat (derived as the total amount of suitable habitat in the study area). Specifically, density was calculated by dividing the total number of detected males by the amount of suitable habitat surveyed, and population size by multiplying the estimated density by the amount of suitable habitat in the area (see Table 1). This closely follows the 2008 study (Santangeli and Dolman 2011).

Results

The total amount of suitable habitat for the Little Bustard has remained largely the same in Abbasanta, but has slightly increased in Campeda (Table 1). Of the total suitable habitat within each of the two areas, the current survey in Abbasanta covered a similar amount (69%) as that covered in 2008 (73%). Sampling effort was lower in Campeda during the present study (12% of the suitable habitat available covered by the survey) compared with the earlier study (45% in 2008).

In 2022, a total of 60 males was detected in Abbasanta and 1 male in Campeda (Table 1 and Figure 1). In Abbasanta, the estimated mean density (males/100 ha) was 2.01, representing a 33% decline since 2008 when a density of 3.02 was reported (Santangeli and Dolman 2011). In Campeda, currently estimated density was 0.09, again about 31% lower than that reported in 2008. As a consequence, the estimated total population size (based on the total available habitat in each area) declined by 33% and 27% in Abbasanta and Campeda, respectively, leading to a current estimated population of 87 and 8 males in these areas, respectively.

While the perimeter of the SPA of Campeda remained unchanged from 2008 to the present, the SPA of Abbasanta was downsized in 2010 by 526 ha to allow infrastructure development (e.g. solar power plants) (Figure 2). In addition, in the same Abbasanta SPA and adjacent to the downsized land (Figure 2), another solar power plant project was recently approved (December 2021), further eroding the perimeter of the SPA. This current and planned downsizing was compensated by an increase in suitable habitat in the rest of the area, thereby explaining the similar amount of suitable habitat in Abbasanta between 2008 and the present (Table 1).

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Table 1. Summary statistics reported separately for each of the two study areas of Abbasanta and Campeda, and from the current (2022) and 2008 study (Santangeli and Dolman 2011). The total extent of each study area, total suitable habitat for the Little Bustard (including pasture and cropland), and suitable habitat covered by the survey (mean ± 95% CI, as well as percentage of all suitable habitat available covered by the survey, are provided within brackets) are all reported in hectares. The density is expressed as the number of detected males by the amount of suitable habitat surveyed (multiplied by 100, hence males/100 ha of suitable habitat). Population estimate is given as the total number of males estimated based on the density and total suitable habitat in the area. The area of each Special Protection Area (SPA) and its percentage covered by the study are also given.

	Abbasanta		Campeda	
Year	2008*	2022	2008*	2022
Total study area (ha)	4,912	4,912	11,555	11,555
Suitable habitat available (ha)	4,314	4,352	8,712	9,260
Suitable habitat surveyed by distance sampling (ha)	3,145 (2,818–3,489; 73%)	2,991 (2,555–3,406; 69%)	3,891 (3,395–4,457; 45%)	1,090 (921–1,280; 12%)
Number of males detected	95	60	5	1
Density (males per 100 ha)	3.02 (2.72–3.37)	2.01 (1.76–2.35)	0.13 (0.11–0.15)	0.09 (0.08–0.11)
Population estimate within study area (based on available habitat present)	130 (117–145)	87 (77–102)	11 (10–13)	8 (7–10)
Area of the SPA (ha)	20,103	19,577	19,578	19,578
% of the study SPA within the surveyed area	24%	25%	59%	59%

*Data extracted from Santangeli and Dolman (2011).

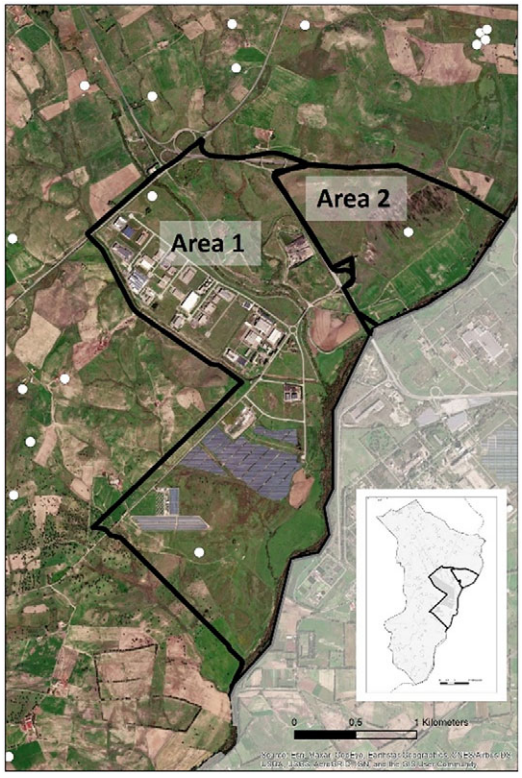

Figure 2. Close up of the eastern section of the Abbasanta study area affected by recent development. The main satellite map shows the Abbasanta plain Special Protection Area (SPA) (ITB023051) that was downsized in 2010 (Area 1), within which solar power plants have been built (visible as blue surfaces in the southern part of Area 1). Area 2 is currently within the boundary of the SPA but within this area a solar power plant project was recently approved (December 2021). Little Bustard males (white circles in the main figure) were found in both these areas during the current study. The inset map shows the location of Areas 1 and 2 within the Abbasanta study area.

Discussion

Current population trends

For the first time in Sardinia, and Italy, systematic surveys repeated with the same methodology over two time periods allowed an update of the status of the Little Bustard, and quantification of population trends, across two areas that are historically important strongholds for the species. We report alarming population declines of 27% and 33% in 14 years in Campeda and Abbasanta, respectively. While the near extinction of the species in Campeda may cast a shadow of pessimism over the species' persistence in Sardinia, and therefore Italy (but see also Santangeli *et al.* 2010), the decline in Abbasanta represents particularly catastrophic news. Abbasanta is thought to represent one of the two current strongholds for the species in Sardinia, supporting an estimated one-third of the whole population on the island (Nissardi and Zucca 2011). The other stronghold, the plain of Ozieri, was not part of this study, but given the declines in other areas, there is an urgent need to also quantify population status and trends there.

The declines reported here (annual rate of approximately 2%) are somewhat lower in magnitude than those reported for the stronghold areas of the species in the Iberian Peninsula (approximately 6%) (Morales and Bretagnolle 2022). The slower rate of decline in Sardinia may be due to the rather traditional pastoral and extensive land use in inland Sardinia that has not notably changed over the past decades, as opposed to the rapid transformations occurring in the cereal steppe of the Iberian Peninsula (Guerrero-Casado *et al.* 2022, Morales and Bretagnolle 2022). Therefore, while alarming, these declines may still leave time and scope for evidence-based conservation management interventions to be implemented.

We acknowledge that not having surveyed all the populations in central-western Sardinia, there is a possibility that the declines found could be partly due to emigration, movement, or displacement. However, we deem this as a rather marginal effect in the

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context of Little Bustard ecology and its distribution in Sardinia. Although interannual movements of individuals, with shifts by over 20 km for males and up to 80 km for females, have been observed in France (Bretagnolle *et al.* 2022), the Little Bustard is strongly site faithful. Moreover, the lek mating system of the Little Bustard is strongly controlled by an Allee effect whereby small populations, for example, below six individuals, become unattractive and slide towards extinction, while larger nuclei tend to be more attractive and therefore increase in numbers (Bretagnolle *et al.* 2022). On this basis, given that Abbasanta represents one of the two strongholds for the species in Sardinia, it should attract, rather than repulse, new individuals, for example, from the surrounding and isolated small nuclei. Also, Abbasanta is separated by over 35 km from the other stronghold of the Ozieri plain, with a large hilly forest in between these two areas. Therefore, it is also unlikely that individuals from Abbasanta would disperse to Ozieri, driving the observed decline in Abbasanta. Moreover, the area of Ozieri is dominated by a cereal pseudo-steppe landscape which nowadays may be under increasing pressure, similar to intensive farming systems (like those in Spain), compared with the pasture-dominated Abbasanta. As a result, the Ozieri landscape may not be as attractive to individuals from Abbasanta that are more used to breeding in pastoral land. Similar biogeographical considerations may also apply to Campeda. However, here the small and declining population may be unattractive, which may cause some males to leave and relocate to other areas, partly explaining the observed decline. Also, we acknowledge that the area of suitable area surveyed in 2022 in Campeda is much lower than that surveyed in 2008. While in theory this may partly affect the comparison in the estimated densities between the two time periods, the survey in 2022 also included those areas of Campeda where Little Bustard was found in 2008. Therefore, it is unlikely that the different area surveyed would have a measurable impact on the population trend reported for Campeda.

Current and emerging threats

Land use in the two areas has remained largely the same, with a landscape mainly dominated by pastoral and extensive cropland. Therefore, contrary to other areas, land-use change, at least until the present, may not be a current threat to the species, at least during the breeding season (Santangeli and Cardillo 2012, Santangeli and Dolman 2011). The observed declines may thus be attributed to subtle breeding habitat degradation, such as declines in the insect prey base essential for reproduction (Wolff *et al.* 2001), increased disturbance, or other causes affecting individual survival beyond the breeding season, such as hunting, both through direct killing or disturbance (Tarjuelo *et al.* 2015).

Over the past decade, an emerging threat to the species, as with many other steppe birds (Traba *et al.* 2007), is represented by the uncontrolled expansion of solar power plants in the region. This threat is eroding suitable habitat for the species in Abbasanta, as is clearly indicated in Figure 2. Over the past years, a total of 65 ha of suitable habitat have already been lost to solar power plant, and 148 ha of suitable habitat will be further lost if proposed plants are developed. The development of solar energy plants typically carries the extension of the power lines, which have been found to be a main threat to bustard species worldwide (Silva *et al.* 2023). Moreover, Abbasanta has been strongly afflicted by a locust plague over the past four years. This plague has caused severe reduction in forage for sheep, posing a threat to the persistence of the local traditional economy. If this traditional pastoral system collapses and is replaced by more profitable ones such as irrigated crops or vineyards, the change will most likely be detrimental to the local Little Bustard population adapted to this extensive land use. Even more worrying, from spring 2022, the Region of Sardinia started a campaign of locust eradication by spraying insecticides (based on deltamethrin, a common chemical insecticide) across the area of Abbasanta. While this poison seems to have low direct toxicity to vertebrates (Rehman *et al.* 2014), being a general insecticide it has the potential to deplete the prey base for insectivorous birds as a side effect (Martin *et al.* 1998, Pascual and Peris 1992). Chicks of the Little Bustard are largely insectivorous during the first months of life (Jiguet 2002), so such pesticides may have detrimental effects on the breeding success of the local Little Bustard population.

The role of protected areas

The two areas of Campeda and Abbasanta are all or partly within SPAs designated for the conservation of the species under the Birds Directive of the European Commission. The downsizing of part of the Abbasanta SPA to make space for infrastructure development (Area 1 in Figure 2), such as solar power plants, represents a worrying sign and precedent. It underscores the fact that the Little Bustard, and most other species, are not safe even within the boundaries of legally protected areas. Unfortunately, this threat of renewable energy sprawl to priority biodiversity areas is becoming increasingly widespread (Pérez-García *et al.* 2022, Santangeli *et al.* 2016a,b), including protected areas (Rehbein *et al.* 2020). Indeed, protected area downgrading, downsizing, and degazettement (PADDD) events have been reported worldwide and are largely driven by resource extraction and infrastructure development (Golden Kroner *et al.* 2019).

Moreover, the recent approval of another solar power plant to be developed within the boundaries of the SPA in Abbasanta (Area 2 in Figure 2) suggests that even the legal status of the SPAs in Sardinia can be over-ruled when large-scale interests are involved. This plan was approved based on an environmental impact evaluation that found the site of no biological importance, and reported no signs of Little Bustard occurrence. As part of the current study, we showed that that is not the case. We found a territorial male right inside the area targeted for development, and a few other males in the surrounding area (Figure 2).

We thus urge the need for local, regional, and national decision-makers and conservation organisations to step up and strongly monitor and potentially take all possible steps to make sure that at least the SPAs designated for the species will not be downsized or degraded. We also urge the need for independent and unbiased environmental impact evaluations of planned development projects.

Conclusions

The magnitude of the decline of the Little Bustard at one of the two population strongholds in Sardinia is alarming. Yet there is scope and time for saving this threatened population if actions are taken quickly. For the immediate future, we call for a full, effective, and durable protection of the SPAs designated for the species to prevent further loss of its habitat. Regular monitoring of the species numbers should also be performed, using robust sampling approaches, across all areas where the species is still extant in Sardinia. This would eventually allow the quantification of the overall population trends and identification of other important and yet unprotected areas where the species habitat should be preserved. While past drivers of the decline are only partly understood and need more

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in-depth investigations, the emerging threats are clear and should be addressed with high priority. This would at least avoid further deterioration of the rather unique and disjunct population of Little Bustard in Sardinia, and ultimately avoid another national extinction of the species.

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